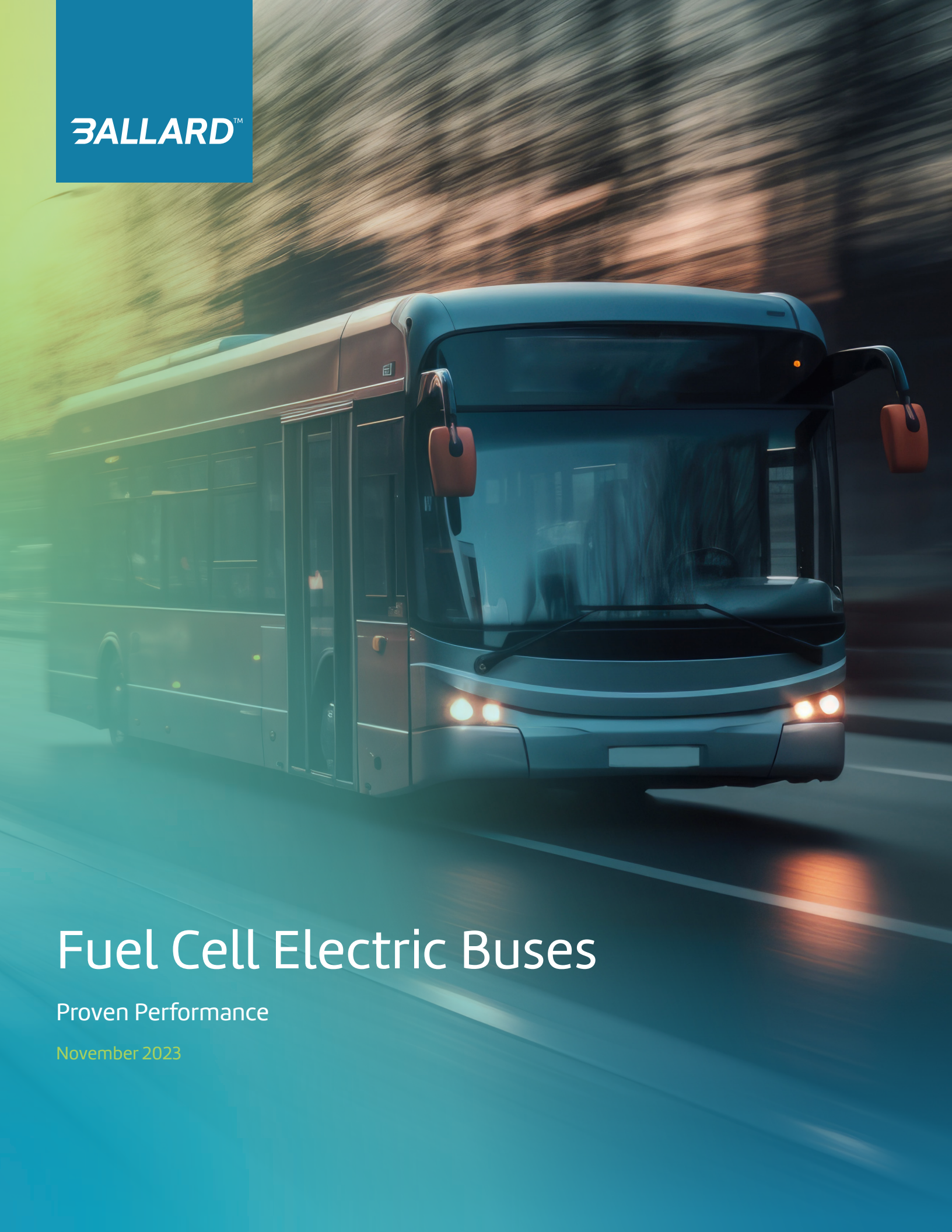




BALLARD™

Fuel Cell Electric Buses

Proven Performance

November 2023

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Introduction

Zero-emission public transport, powered by renewable energy, is fast becoming the next stop for transport networks in cities across the world. With increasing numbers of fuel cell electric buses in operation, hydrogen power is now an important part of the solutions available for operators to meet their net zero targets – while providing passengers with an efficient, clean, and sustainable mode of transport.

Ballard delivers fuel cell power for a sustainable planet. We use our considerable fuel cell expertise – built up over 40 years – to provide real-world solutions to global transit customers.

Today, Ballard Power Systems has more than 1,600 fuel cell electric buses in service in over 70 cities worldwide, with several new fleets due to be launched in the 2023-24 timeframe – making Ballard the largest fuel cell supplier with more than 150 million kilometers of proven on-road experience.

Fuel cell electric buses fueled with hydrogen are the only zero-emission technology to offer one-to-one replacement of diesel fleets, with proven range, complete route flexibility, short refueling time and optimized depot space utilization. Hydrogen fuel cells are the most viable solution to reduce emissions and create a cleaner future without compromise.





The Solaris Urbino 18 Hydrogen is powered by Ballard's FCmove®-HD+ 100kW fuel cell engine

Fuel Cell Electric Buses

Fuel cells are an established, mature, zero-emission technology for heavy-duty powertrains. For more than a decade, buses powered by hydrogen have been in daily use. The technology has accumulated significant operational, reliability, and durability data through commercial operation in fleets around the world. Fuel cell electric buses have demonstrated consistent performance throughout long daily drive cycles and in a range of challenging climates, weather conditions and geographies.

Fuel cell electric buses share the design and major components (like the electric drive) with battery electric buses. The difference lies in the smaller battery and onboard power generator (the fuel cell power module) providing electricity to the electric drive motor and recharging the batteries. Hydrogen tanks store the energy needed for bus operation and the high energy density by weight of hydrogen allows the storage of over 1,000kWh onboard without compromising passenger capacity.

Hydrogen-powered fuel cell electric buses can operate on all urban bus routes without compromise and are the only zero-emission technology to offer full vehicle capability – including gradeability, highway speeds and long range – in all operating environments.

Fuel cell electric buses can perform faultlessly for an entire 14-hour shift even on the most arduous routes, at more than twice the fuel efficiency of conventional diesel or compressed natural gas (CNG) technologies.

The fuel cell electric bus provides the same benefits that a battery electric bus does – zero-emission, low noise, high performance, and improved passenger comfort – with key additional advantages:

- Extended range for route and service flexibility
- Power to maintain speed on the most demanding routes
- Rapid refueling to ensure high utilization, with scalable infrastructure
- Utilization of fuel cell heat for HVAC (no need for diesel heater)
- Sustainable solution with low-carbon footprint (cradle to grave)

Ballard offers fuel cell engines in a range of 45kW–120kW power outputs to meet different bus sizes, hybridization strategies, and application requirements.

Today, fuel cell electric buses are offered as a standard option in a bus manufacturer's electric platform portfolio. Many bus manufacturers are accelerating offerings for fuel cell electric bus configurations on their electric bus platforms.

Fuel Cell Electric Bus Benefits

RANGE

The operating range of fuel cell electric buses is determined by the quantity of hydrogen fuel stored onboard the bus. Typical hydrogen storage capacity on buses will range from 30–50kg of gas in rooftop-mounted compressed gas tanks.

Based on the onboard storage capacity, hydrogen-powered buses can achieve ranges from 400–550km.

The Orange County Transportation Authority (OCTA) in California, which currently operates 10 fuel cell electric buses, reports the range of a fuel cell bus with a 50kg hydrogen tank is 600km (450km with a 37.5kg hydrogen tank), compared to 255–300km for a battery electric bus with a 400+ kWh battery.

These ranges have been demonstrated on passenger service routes even with auxiliary heating or cooling systems operating.

FUEL CELL ENGINE DURABILITY

The fuel cell power module generates direct current power by converting hydrogen gas and oxygen from the air to energy via an electrochemical process similar to batteries. Unlike batteries, fuel cell performance is not diminished by charge-discharge cycles. Fuel cells keep producing electricity as long as hydrogen fuel is fed to the fuel cells.

The fuel cell module is a completely integrated system designed with robust balance-of-plant components to improve reliability, to deliver an expected operating lifetime greater than 25,000 hours. Some fuel cell electric buses powered by Ballard have now operated for more than 10 years in the field, exceeding 35,000 hours of revenue service with no fuel cell stack replacement.

The general wear and tear of materials will, however, eventually impact some of the engine components, subsequently

affecting fuel cell performance, including output power and efficiency. This degradation is slow and can be monitored through predictive maintenance to prevent engine failure.

Over time, some components will have to be replaced – like in a diesel engine – and the fuel cell stack requires refurbishment at least once during the 12–14-year life of the fuel cell electric bus. Once refurbished, fuel cell engines can continue to be part of a transit bus's second life.

Ballard's FCmove® fuel cell engine achieves high performance by using optimized operating pressure and humidification to ensure reliability and improve durability in a broad range of operating conditions.



FCmove®-HD+ 100kW



FCmove®

FUEL CELL MODULE AVAILABILITY

Ballard's expert Customer Care team tracks a fuel cell electric bus fleet powered by Ballard's FCmove® fuel cell engines daily. The modules collect up to 120 data points every minute, and the data is typically transmitted back to Ballard every 24 hours.

Based on a fleet of more than 100 fuel cell electric buses monitored by Ballard in 2022-23, the average availability of FCmove® fuel cell engines in operation in Europe and the U.S. was 98%.



Ballard's FCmove®-HD fuel cell engine is integrated in Solaris's Urbino 12 Hydrogen via a roof-top module

FUEL CONSUMPTION

The actual hydrogen fuel consumption of a fuel cell electric bus depends on the duty cycle of each specific bus and considers the passenger load, route, speed, and heating and cooling requirements.

The fuel required to power the bus electric drivetrain on a flat route is around 5–6kg/100km. The addition of an auxiliary load, such as heating or cooling and route topologies, will increase fuel consumption.

Today's current generation of fuel cell electric buses demonstrate an average fuel consumption of 8kg/100km.

The Joint Initiative for hydrogen Vehicles across Europe (JIVE) project bus fleet has recently demonstrated an average fuel consumption of between 6.3–9kg/100km. AC Transit's bus fleet in California has reported an average of 8.2kg/100km¹.

AC TRANSIT 5X FLEET RESULTS²

FLEET	DIESEL (BASELINE)	DIESEL (HYBRID)	FUEL CELL ELECTRIC	BATTERY ELECTRIC
Technology Type	Diesel	Diesel Hybrid	PEM Fuel Cell	Lithium-Ion Battery
Bus Quantity	5	5	5	5
Bus Year	2018	2016	2019	2019
Length	40ft (12m)	40ft (12m)	40ft (12m)	40ft (12m)
Energy/Fuel Capacity	120 Gallons (454l)	120 Gallons (454l)	38kg	466kWh
OEM Range Specifications	480 miles (770km)	700 miles (1,125km)	300 miles (480km)	200 miles (320km)
Date Summary (June 2020–July 2022)				
Total Fleet Mileage	757,363	1,235,654	452,103	272,046
Operating Cost/Mile (Average)	1.58	2.02	2.03	1.65
Cost/Mile (W/Credits)	1.55	1.98	1.32	0.64
Total Emissions (CO ₂)	1,103	622	0	0
Fleet Availability (Average)	92%	68%	75%	58%
Efficiency (Average) DGE	4	5.3	8.4 (8.2kg/100km)	17.2 (1.4kW/km)
Maintenance Cost/Mile	0.93	1.54	0.97	1.2

¹ <https://www.actransit.org/zeb#Reports>

² Zero Emission Transit Bus Technology Analysis: Average Data from Volume 1–4



OPERATING COST

In the past decade, with limited production volume, fuel cell electric bus price – related to buses in transit operation – has decreased by approximately 60%, primarily driven by advancements and innovation in technology and product improvements.

For some applications, fuel cell electric buses currently offer parity with battery electric buses when it comes to the total cost of ownership and are projected to be less expensive to run than battery and traditional internal combustion engine vehicles for several use cases within the next 10 years.

With future scale-up in production driven by truck market demand and additional product innovations, Ballard anticipates a further reduction in the overall fuel cell system cost of approximately 70% by 2030.

Ballard's roadmap to meet this cost reduction involves:

- Strategic industry partnerships – accelerating fuel cell industrialization and leveraging volume from truck market
- Ballard's stack cost reduction initiatives – including advanced manufacturing processes increased power density and lower cost materials
- Optimize battery-fuel cell integration to improve vehicle performance and reduce lifecycle cost
- Recycling and refurbishments increasing lifecycle and improving fuel cell electric bus residual values

Today, the average maintenance cost for a fuel cell electric bus is around \$0.30/km, depending on operating conditions. This is based on data collected from the latest generation of buses currently in operation in Europe and the U.S.

Fuel cell bus competitiveness is improving year-over-year, leading major transit operators to include and scale hydrogen in their zero-emission transition plans. Key factors in ensuring this accelerated reduction in costs include:

- A reduction of hydrogen fuel cost, with significant investment in low-carbon hydrogen production and support from government policies ('Fit for 55' and the Inflation Reduction Act, e.g.)
- An increase in the durability of hydrogen powertrain components
- A decrease in capital costs through scaling-up of fuel cell systems and hydrogen tank production

Based on an average of 70,000km per year and a 12-year bus lifetime, the fuel cell power module's total life maintenance cost is expected to be less than \$0.10/km (preventive and corrective maintenance).

When comparing different options for zero-emission, it is important to consider operational requirements beyond vehicle and fuel costs which could impact total cost of ownership, including:

- Number of zero-emission vehicles required to replace diesel fleets
- Impact on operation; route, schedule and refueling processes
- Possible need for on-route charging infrastructure
- Power requirement at depot level and power availability when scaling up zero-emission bus fleet
- Space requirement to refuel/recharge bus

Vehicle Operation

Ballard-powered transit buses operating for a sustained period across global regions have experienced a wide variety of operational conditions and have demonstrated the following features:

- Fuel cell power systems operate from -40°C to $+50^{\circ}\text{C}$ ambient temperature, with freeze start from -25°C
- Consistent bus performance and behavior during entire drive cycle
- Consistent bus performance during all seasons – fuel cell engine is not affected by ambient temperature
- Maintain batteries within a healthy state of charge and avoiding deep discharge cycles
- Emissions-free heating for passenger compartment – from fuel cell power and waste heat, not from diesel or gasoline-burning heaters



New Flyer's Xcelsior CHARGE is powered by Ballard's FCmove[®]-HD+ and is in operation in over 100 buses across North America

Sustainability

Fuel cell and hydrogen technologies are playing an important role in the decarbonization of transportation – helping to address climate change, air quality, and net zero targets. As such, it is important to quantify the greenhouse emissions (GHGs) associated with fuel cells and identify areas where emissions could be decreased to ensure sustainability.

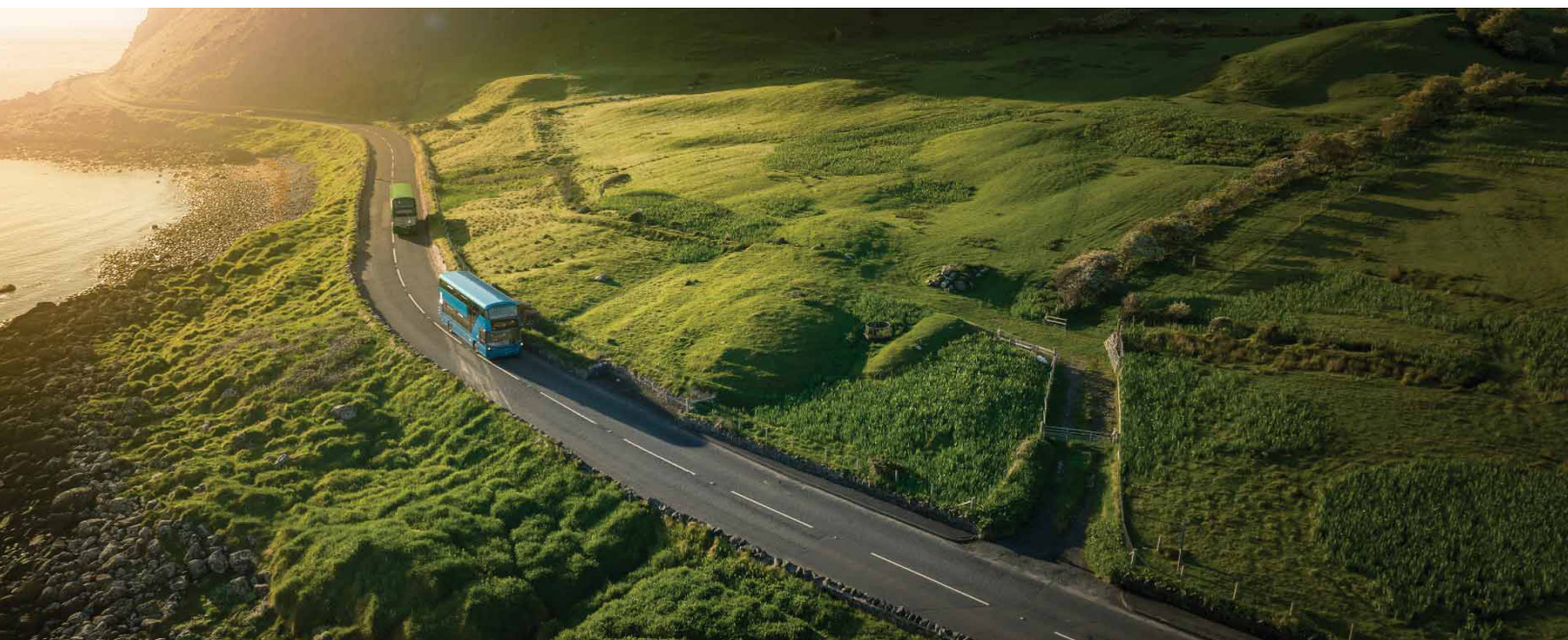
With more than 30 years of fuel cell manufacturing experience, Ballard has developed industry-leading processes designed to minimize the energy intensity and environmental impact of both production and disposal of its products.

Ballard recently undertook a lifecycle assessment (LCA) of its 70kW FCmove®-HD module. The LCA boundary was cradle-to-gate, meaning all GHGs produced upstream of Ballard for this product were quantified. The LCA for the FCmove®-HD fuel cell module determined that each module generates 5.1 tons of CO₂ (GHG emissions) during its production from cradle-to-gate. There are 75% fewer emissions generated in the production of a fuel cell power train with a 70kW fuel cell system than a 350kWh battery-only system.

The process for recycling hydrogen fuel cells is well established, and Ballard has extensive experience in this area.

Every year, Ballard recycles and refurbishes several thousand fuel cell stacks. At the end of a fuel cell product's useful life, processes ensure the efficient recovery of valuable precious metals and materials that minimize waste from entering the landfill. Ballard fuel cell stacks use no cobalt, lithium, or rare earth materials. Using carbon in the stack bipolar plate design enables the reuse of plates and thereby curtailing waste.

During the fuel cell stack refurbishing process, Ballard integrates a new membrane electrode assembly (MEA) with the re-used bipolar plates and hardware. The old MEA is sent to a specialized facility that reclaims 95% of the platinum.



Ballard powers Wrightbus' double-deck Streetdeck Hydroliner and single-deck Kite Hydroliner fuel cell electric buses – now servicing UK public transport routes



Van Hool's A330 is powered by Ballard fuel cells and is in service with transit operator RVK in Germany

Conclusion

With nearly two decades on the road and millions of kilometers in passenger service, fuel cell electric buses have proven their performance in different climates throughout the years on challenging routes up to 18 hours a day.

Fuel cell electric buses powered by low-carbon hydrogen complement battery electric buses to achieve a faster transition to 100% zero-emission bus fleets.

Today, more than 1,600 fuel cell electric buses powered by Ballard technology are in operation worldwide. Current generation zero-emission vehicle deployment provides a 1:1 replacement for conventional buses, the latest centralized and scalable solutions using hydrogen as a clean and flexible fuel are being increasingly adopted and inspired by the growing number of successful real-world use cases, rising numbers of transit agencies and bus operators are migrating to decarbonized fleets without affecting service or current operational processes.

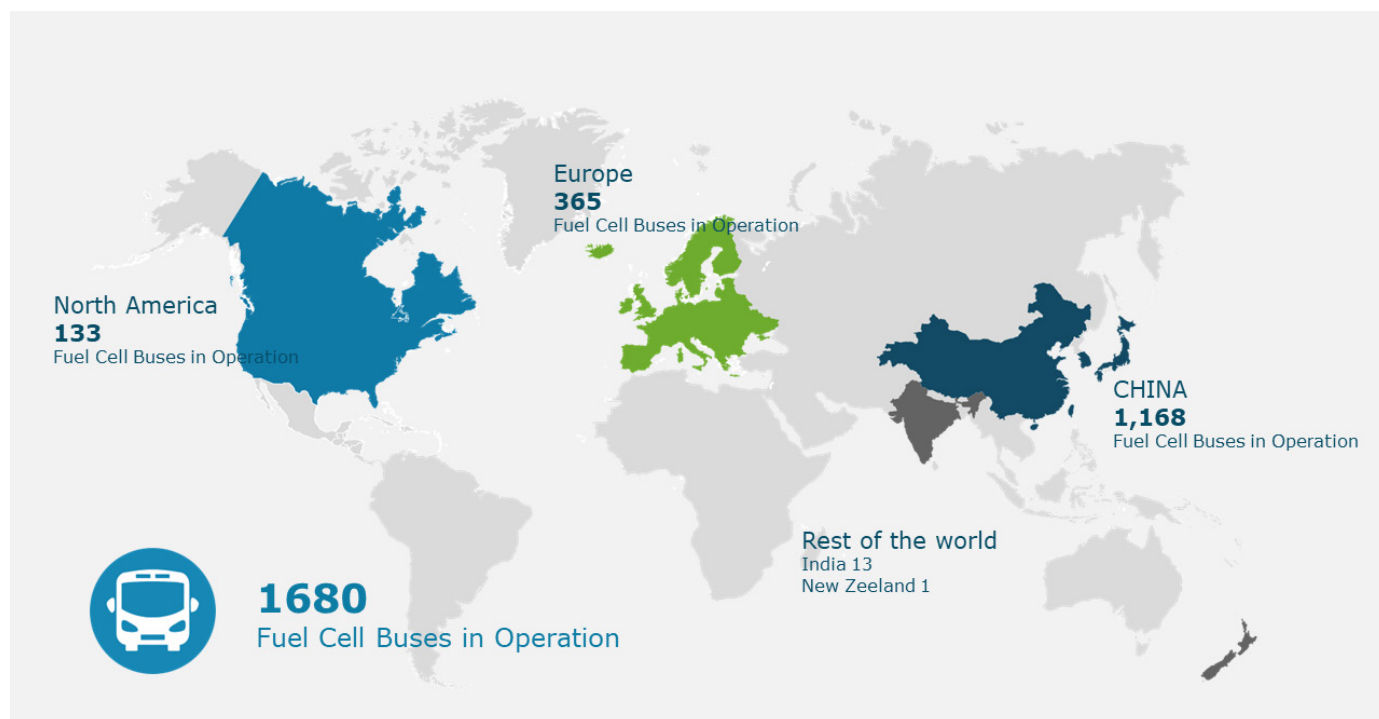
As long-term partners with a commitment to public transport operators and OEMs, Ballard has expert industry knowledge, highly skilled staff, and comprehensive support systems in place to inform, train and provide exceptional customer care dedicated to the accelerated adoption of fuel cell electric buses worldwide. Offering consultation, workshops, and education to assist in fleet deployment and the development of associated infrastructure, Ballard supports the customer experience from start to finish.

Appendix

FUEL CELL ELECTRIC BUSES POWERED BY BALLARD ENGINES

- New Flyer Xcelsior CHARGE FC – powered by Ballard’s FCmove®-HD+ 100kW fuel cell engine
- Solaris Urbino 12 Hydrogen – powered by Ballard’s FCmove®-HD 70kW fuel cell engine
- Solaris Urbino 18 Hydrogen – powered by Ballard’s FCmove®-HD+ 100kW roof-top fuel cell engine
- Wrightbus Streetdeck Hydroliner – powered by Ballard’s FCveloCity™-HD 85kW fuel cell engine
- Wrightbus Kite Hydroliner – powered by Ballard’s FCmove®-HD 70kW fuel cell engine
- ADL Enviro400 FCEV – powered by Ballard’s FCmove®-HD 70kW fuel cell engine
- Van Hool A12 – powered by Ballard’s FCmove®-HD 70kW fuel cell engine
- Van Hool A330 – powered by Ballard’s FCmove®-HD+ 100kW fuel cell engine
- Karsan e-ATA HYDROGEN – powered by Ballard’s FCmove®-HD 70kW fuel cell engine
- NesoBus Hydrogen – powered by Ballard’s FCmove®-HD 70kW fuel cell engine

FUEL CELL ELECTRIC BUSES POWERED BY BALLARD IN OPERATION AROUND THE WORLD



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